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I, JULIE BILLINGSLEY, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. 2003904198 for a patent by TELE-IP LIMITED as filed on 11 August 2003.

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Patents Act 1990

PROVISIONAL PATENT SPECIFICATION

Patent Application No:
Application Date:

APPLICANT: Tele-IP Limited [ACN 010 568 804]

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INVENTION TITLE: Detection of Wake Vortexes and the like in the Lower Atmosphere

The invention is described in the following statement:–

TITLE: Detection of Wake Vortices and the Like in the Lower Atmosphere

TECHNICAL FIELD

The present invention is generally concerned with sodar apparatus, methods and systems for use in detecting, recording and/or displaying short-duration or anomalous atmospheric turbulence such as wake vortices shed from large aircraft, large wind-generator propellers or the like, and such as occasional down-wind vortices or turbulence generated by tall man-made or natural structures in a prevailing wind. This invention is therefore applicable to the detection and/or display of aircraft wake vortices in the vicinity of major airports to augment airport safety and traffic management.

In other words, the type of turbulence with which this invention is typically concerned is that which occurs in calm, or relatively mild or constant weather conditions and is not amenable to prediction by weather forecasting techniques. Indeed, the vortices of concern seldom form and very rarely persist in gusty or stormy conditions where there is high atmospheric mixing. The energy of any vortex that does form under these conditions tends to be quickly dissipated.

BACKGROUND TO THE INVENTION

This specification is to be read in conjunction with our earlier Australian provisional patent application 2003/900878 and our earlier international application PCT/AU02/01129, both of which relate to sodar systems using long pulses encoded in a 'pulse compression' manner, using over-sampling of received echoes for good resolution and processing gain, and using complex Fourier-domain processing of the sampled echoes to achieve further discrimination and processing gains in the signal-to-noise ratio. Such pulses – generically called 'chirps' – were at least 300 ms in duration and, preferably, lasted for tens of seconds. The pulse-compression technique employed was preferably a linear increase or decrease in phase (tone) over the duration of the pulse; for example, a steady increase in tone from 500 to 1500 Hz, or a steady decrease in tone from 1500 to 500 Hz. The methods disclosed involved 'listening

while sending'; that is, echoes are received and processed while transmission of the chirp is still under way. This technique not only allows very high system and processing gains that result in exceptionally good s/n (signal to noise ratio), but it also enables atmospheric discontinuities that occur close to the ground to be detected. Since prior art systems could not 'listen while sending', it was necessary to use short powerful pulses for short-ranges and to suffer the resulting very poor system and processing gains. Such prior art sodars were essentially incapable of detecting and displaying wake vortices.

While the sodar systems disclosed in our prior applications were capable of detecting wake vortices and of monitoring wind conditions in the vicinity of airports with much greater sensitivity and precision than was previously possible in the art, they still had difficulty in displaying the 'life' of a vortex; for example, tracking the wind shear disturbances formed by a landing aircraft as they form and fade and as they travel to the ground or dissipate over a period of minutes.

For brevity, the disclosures in our aforementioned applications are regarded as being incorporated herein, including the extensive discussion of the prior art contained in the specifications of those applications. In addition, some of the terminology that is used herein is explained or defined in those specifications.

OUTLINE OF THE INVENTION

The present invention is based upon the realization that the short-term atmospheric turbulence of interest is difficult to reliably detect, isolate and display by sodar methods because it is embedded in 'normal' atmospheric discontinuities (perhaps including background turbulence that is of lower intensity and more chaotic or less structured) that generate masking outputs from sodar systems. [For the sake of convenience, the anomalous turbulence of interest will be referred to as a 'vortex' or 'vortices'.]

Thus, from one aspect, the present invention involves, first, using the sodar system to monitor the normal conditions prevailing in the absence of an atmospheric vortex of interest and generating a reference signal indicative of such

normal conditions, second, using the sodar system to monitor the vortex of interest to generate a turbulence signal and, third, comparing the reference and turbulence signals to discount common components thereof and to enhance non-common components due to the anomalous turbulence under investigation. The result of the comparison can be referred to as the vortex signal.

It will be appreciated that the method and system suggested requires some means of detecting the presence of a vortex of interest so that the turbulence signal can be generated and the reference signal or signals can be identified. This can be done in a variety of ways. The sodar system itself can be used to detect the presence of a vortex that exceeds a preset threshold of intensity (eg, wind shear) and that is within a predetermined distance range. This method is suitable where the distance range is of the order of kilometers and the turbulence is substantial – for example, a 'dust devil' or tornado. Where low altitude aircraft wake vortexes in the vicinity of airports are of interest, normal conditions can be assumed to preside prior to the approach of an aircraft and after some minutes have passed since the last aircraft landing. In this method, normal and turbulence measurements can be initiated manually or automatically using visual cues, or the switch from normal to turbulence monitoring can be effected automatically using acoustic cues (eg, listening for a large approaching aircraft).

Where vortexes from wind generators are of interest (and are assumed to be shed continuously) the reference signal can be generated by using a second reference sodar system located sufficiently far from the generator that it is clear of its vortexes. This technique can also be used for aircraft wake detection. For example, where vortexes from landing aircraft are of interest, a 'reference' sodar can be arranged away from the zone where landing vortexes are expected and its signals can be used as the normal or reference signals for comparison with turbulence signals generated by a second sodar arranged to monitor the zone where landing vortexes are likely. Thus the reference signal is displaced from the turbulence signal in space instead of, or in addition to, displacement in time.

The atmospheric parameter(s) used by the sodar system to identify the presence of a disturbance of interest need not be the same as that or those used to generate the normal, reference and vortex signals or displays. For example, detection of vertical wind speed above a predetermined threshold may be used to trigger the switch from normal/reference to turbulence signal generation, but the parameters that make up the reference and turbulence signals may include horizontal wind shear, wind velocity, virtual temperature, refractive index etc, with or without the inclusion of the vertical wind speed parameter. Similarly, the generation of the vortex signal from a comparison of the normal and reference signals may involve comparison of all component parameters of each signal, or comparison of only selected parameters.

While we have found that it preferable to monitor multiple parameters to characterize the reference and turbulence signals, we have also found that vortexes can often be best visualized by the comparison of only selected ones of the component parameters. The parameters that give the best results can vary with the nature of the vortex and the ambient/normal conditions, so it is not always apparent which parameters to select. Some trial and error may be involved. Our preference is to separately compare multiple parameters and to select those with the most contrast to generate the vortex signals, or to simply effect the comparison and then assess which is the most useful or informative vortex signal to employ. Sometimes, the display of multiple vortex signals side-by-side provides the optimal presentation of the results.

Our above referenced international patent application disclosed methods and apparatus for deriving atmospheric parameters using phase/Doppler information within the returned echoes, while our above referenced provisional application related to similar methods and apparatus for deriving atmospheric parameters using amplitude/signal-strength information within the returned echoes. Both employed pulse-compression / matched-filter Fourier methods to process the raw acoustic echoes. Accordingly, phase and/or amplitude related parameters may be used in the invention disclosed herein.

Finally, we have found that there are differences in the echoes returned from forward and reverse linear chirps that can be exploited when comparing reference and turbulence signals. In other words, a parameter (eg, returned signal level) generated using forward chirps is not always the same as the same parameter generated using a reverse chirp and, indeed, the difference can be of significant assistance in generating, discerning or depicting a vortex signal.

DESCRIPTION OF EXAMPLES

Having portrayed the nature of the present invention, particular examples will now be described with reference to the accompanying drawings. However, those skilled in the art will appreciate that many variations and modifications can be made to the chosen examples while conforming to the scope of the invention as outlined above.

Brief Summary of the Drawings

In the accompanying drawings:

Figure 1 is a diagram of an airport runway extending East - West with a pair of sodar systems for use in detecting and displaying vortexes left by landing aircraft.

Figure 2 is a time-series of graphs showing the East vortex phase signal derived by differencing the East reference and the East turbulence phase signals.

Figure 3 is a time-series of graphs showing the West vortex phase signal derived by differencing the West reference and the West turbulence phase signals.

Figure 4 is a series of curves, one per landing aircraft, showing the variation with time of the maximum East – West vortex phase signal (which corresponds to the maximum wind shear) of Figure 3.

Figure 5 is a time-series of graphs showing the East vortex amplitude signal derived by differencing the East reference and the East turbulence amplitude signals.

Figure 6 is a time-series of graphs showing the West vortex amplitude signal derived by differencing the West reference and the West turbulence amplitude signals.

Figure 7 is a series of curves, one per landing aircraft, showing the variation with time of the height of the maximum East – West vortex signal in the vicinity of the sodar system.

It will be appreciated that the disclosures in our aforementioned applications offer many parameters that can be generated for use in the present invention and provide examples and details of the way in which those parameters are measured or generated. It will be convenient to describe many of them in the context of a sodar system capable of detecting and displaying – in near real-time – wake vortexes caused by large aircraft landing at an airport during relatively calm conditions at altitudes of below 300 m. It is to be noted that prior art sodar systems have been unable to detect and portray wake vortexes at such low altitudes due to their relatively poor s/n (among other factors). Indeed, no prior art system – RADAR, LIDAR and RASS included – have met this challenge.

Figure 1 is a diagram showing a runway 10 that is aligned East - West, a sodar system 12 located under the glide path, an aircraft 14 that is about to land and a vortex 16 generated by the aircraft. The sodar system is one of those disclosed in our referenced applications in which four receivers are placed on the cardinal points of the compass around a transmitter, only the East and West receivers Re and Rw being shown along with the transmitter Tx. The substantially vertical path of the transmitted signal is shown at 18, the path of the echoes received by Re being shown at 20 and the path of those received by Rw being shown at 22. It will be appreciated that the lateral displacement of the N, S, E & W receivers from the transmitter results in Doppler components in the chirp echoes received by each receiver that are indicative of a combination of horizontal and vertical wind components.

Though not shown in Figure 1, sodar system 12 may also include a central receiver mounted with its axis vertically aligned with transmission axis 18. The Doppler components of the echoes received by this fifth receiver will be more indicative of vertical wind speed.

As taught in our earlier applications, the Doppler components due to vertical wind speed variation, which turn up in the echoes received by Re and Rw can be substantially discounted by subtracting the phase components of the outputs of these receivers (after suitable processing) to give E – W wind-shear. N – S wind-shear can be similarly derived and then combined with the E – W wind-shear to give horizontal wind velocity (ie, horizontal wind speed and bearing).

The system of Figure 1 can also be used – as also taught in our referenced applications – to generate outputs indicative of the variation of the amplitude of suitably processed receiver signals with altitude, relatively strong reflections being indicative of atmospheric discontinuities due to wind shear, temperature and/or moisture change with altitude.

Sodar system 12 may be employed to generate reference data sets of phase and/or amplitude components during calm or normal times (without the noise of landing aircraft or the presence of any wake vortex. Alternatively, a second sodar system positioned away from the approach zone of the runway can be used to generate the reference signal. In Figure 1, the second sodar system is shown at 12a.

Use of Horizontal Wind Velocity Components

As disclosed in our referenced international application, the transmitted chirp can be an audio pulse that increases linearly in phase/frequency from about 600 to about 1250 Hx over a period of 46 s duration. The echoes received by each receiver are processed by a dedicated PC to generate signals indicative of phase-shift with time/altitude, incremental or differential phase differences (when corrected for range) being indicative of wind speed. While it is likely that a substantial wake vortex will make its presence felt in all horizontal and vertical wind velocity signal components, the effect will not be uniform across all components and may be much more pronounced in one than in another.

Though not illustrated here, a graph or data-set is generated every six seconds of the incremental variation of the extracted phase component of the Re signal with height of sodar system 12 or 12a during calm or 'normal' periods. One of these graphs, or more preferably, an average of more than one, is stored as the reference signal. This phase reference signal is regularly updated in the absence of landing aircraft.

It has already been pointed out that the extracted phase component of the signal from Re is a mixture of phase elements attributable to both horizontal and vertical air movements. It has been found that such 'mixed' phase signals are quite sensitive to wake vortexes, which after all have both strong vertical and horizontal wind speeds. Though not illustrated here, a graph or data-set is taken every six seconds of the extracted phase component of the processed output of East receiver Re shortly after the passage of an aircraft through the zone monitored by sodar 12. Some air velocity peaks due to the wake vortex left by the aircraft may

be discernable but rather indistinctly. Thus, these graphs and data-sets form the aforementioned phase turbulence signals.

The selected reference signal derived as just described is then subtracted from each turbulence signal to generate the series of signal graphs of Figure 2, which thus comprise the aforementioned phase vortex signal. It will be seen that the series of wind velocity peaks, marked X, that are indicative of the presence of a wake vortex are more pronounced and distinct than in the turbulence signals.

A similar set of phase outputs for each of the other receivers can be generated in the same way as described with respect to the East receiver Re. Thus, West reference and turbulence signals are obtained and differenced to yield the West phase vortex signal shown in Figure 3 that also reveals velocity peaks Y due to the vortex.

As taught in our aforementioned applications, the extracted phase components of the East and West reference and turbulence signals that are due to vertical wind velocities can be effected removed by differencing the corresponding East and West signals on the assumption that there will be little differential variation in vertical wind over the relatively small volume of air from which the echoes received by Re and Rw are generated. Of course, any phase components extracted from the Re and Rw signals that are due to a net horizontal wind velocity will also be removed by differencing, since those components are also common to the Re and Rw signals. The result is a differential E – W phase signal that is indicative of East – West wind shear. Often, the resultant wind shear peaks due to the wake vortex are even more pronounced than the wind velocity peaks of the East and West vortex signals. The wind-shear data-sets or graphs are thus an alternative representation or view of the vortex signal, which can be referred to as a 'secondary vortex signal to distinguish it from the East and West wind velocity vortex signals derived above. However, other methods of generating secondary vortex signals are envisaged and referred to below.

An idea of the persistence and severity of the wake vortexes left by successive aircraft landing over a period of some hours on one day is shown in Figure 4. In this Figure the maximums of the secondary vortex signals are plotted against time following the passage of an aircraft. While dangerous peak wind shears are evidenced, they are short lived in the samples of Figure 4 due to relatively windy atmospheric conditions on the day. Vortexes with longer life times have been observed on days with little or no wind.

It will be appreciated that the approach of a large aircraft can be detected acoustically using the receivers of sodar system 12 itself, or using a microphone especially arranged and adapted for the purpose. Upon the detection of the approaching aircraft, the immediately previous soundings are stored (as a series of individual soundings or as a rolling average thereof) for later use in the generation of the vortex signals. The next set of soundings are then stored as turbulence signals taken over a preset time interval. After which the stored reference and turbulence signals are compared to generate a set of primary or secondary vortex signals.

It has been noted above that, instead of using time-spaced reference and turbulence signals, these signals can be derived at the same time from physically spaced sodars, as illustrated in Figure 1 by sodars 12 and 12a.

As already noted, our referenced prior applications also disclose means for extracting the amplitude components of received signals using matched filter and complex Fourier processing methods. These extracted amplitude signals can be used in analogous ways to the extracted phase signals as described above. Thus, a time series of graphs or data-sets, taken at six second intervals of amplitude signals derived from echoes processed by receiver Re during a normal or calm period free of landing aircraft, are used to form an East amplitude reference signal. A similar series of graphs or data-sets is then extracted from echoes received by Re following the passage of a landing aircraft and, thus, comprise a set of turbulence amplitude signals. The amplitude peaks due to reflections or refractions from air discontinuities caused by the wake vortex will normally be

visible. Differencing of the East amplitude reference and turbulence signals thus yield the set of East amplitude vortex signals shown in Figure 5 in which the vortex peaks, marked N, are more pronounced and of longer duration. In a similar way, West amplitude vortex signals were extracted and derived with the result shown in Figure 6

If desired, extracted amplitude vortex signals derived from East and West receivers Re and Rw can be differenced (as described with respect to the phase components) and used to derive secondary amplitude vortex signals indicative of differential refractive variation in the field being monitored. If the reference and turbulence signals are derived at substantially the same time from different spaced sodars (eg, sodars 12 and 12a of Figure 1), then the secondary amplitude vortex signal can be understood as representing 'refractive shear' between the two locations.

Figure 7 is a series of curves, one per landing aircraft, derived from the amplitude vortex signals for each aircraft, showing variation of the altitude at which the maximum peak of the vortex signal occurred for successive soundings taken at intervals after the passage of the aircraft.

Again, as noted with respect to extracted phase components, it is not necessary to use the same sodar system to generate both the reference and the turbulence signals. This can be done using different sodar systems that are spaced apart, as with systems 12 and 12a of Figure 1. In other words, physical spacing between the taking of reference and turbulence samples is an alternative to time-spacing.

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Tele-IP Limited
By its Attorney

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Paul A Grant

8 August 2003

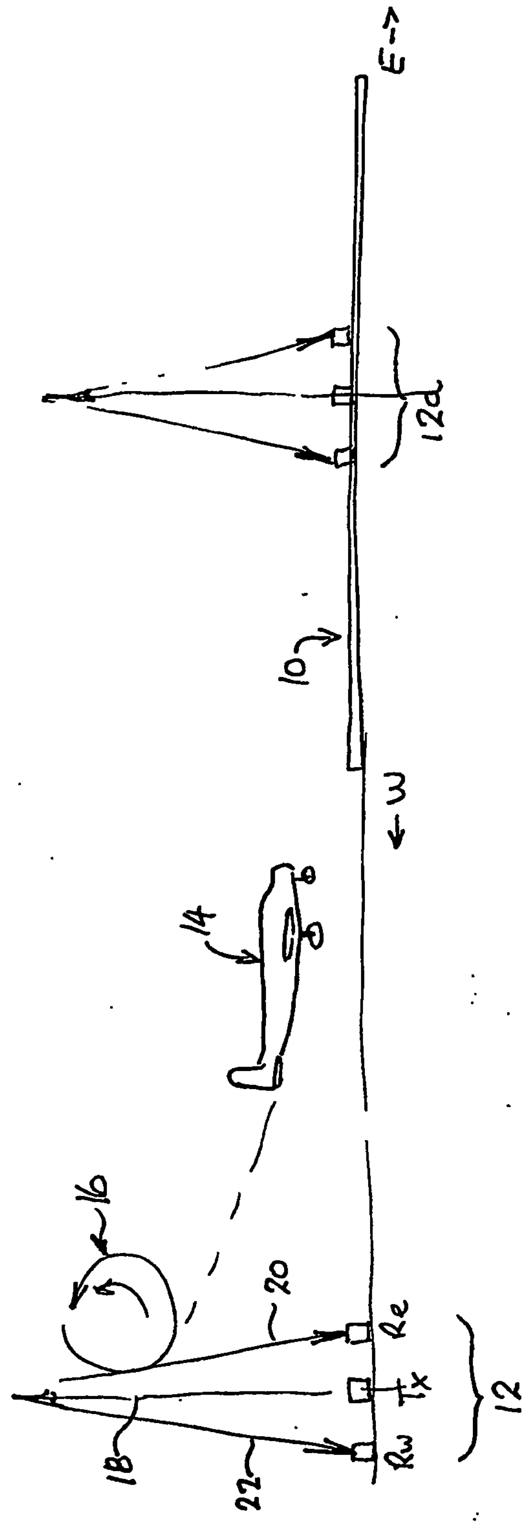
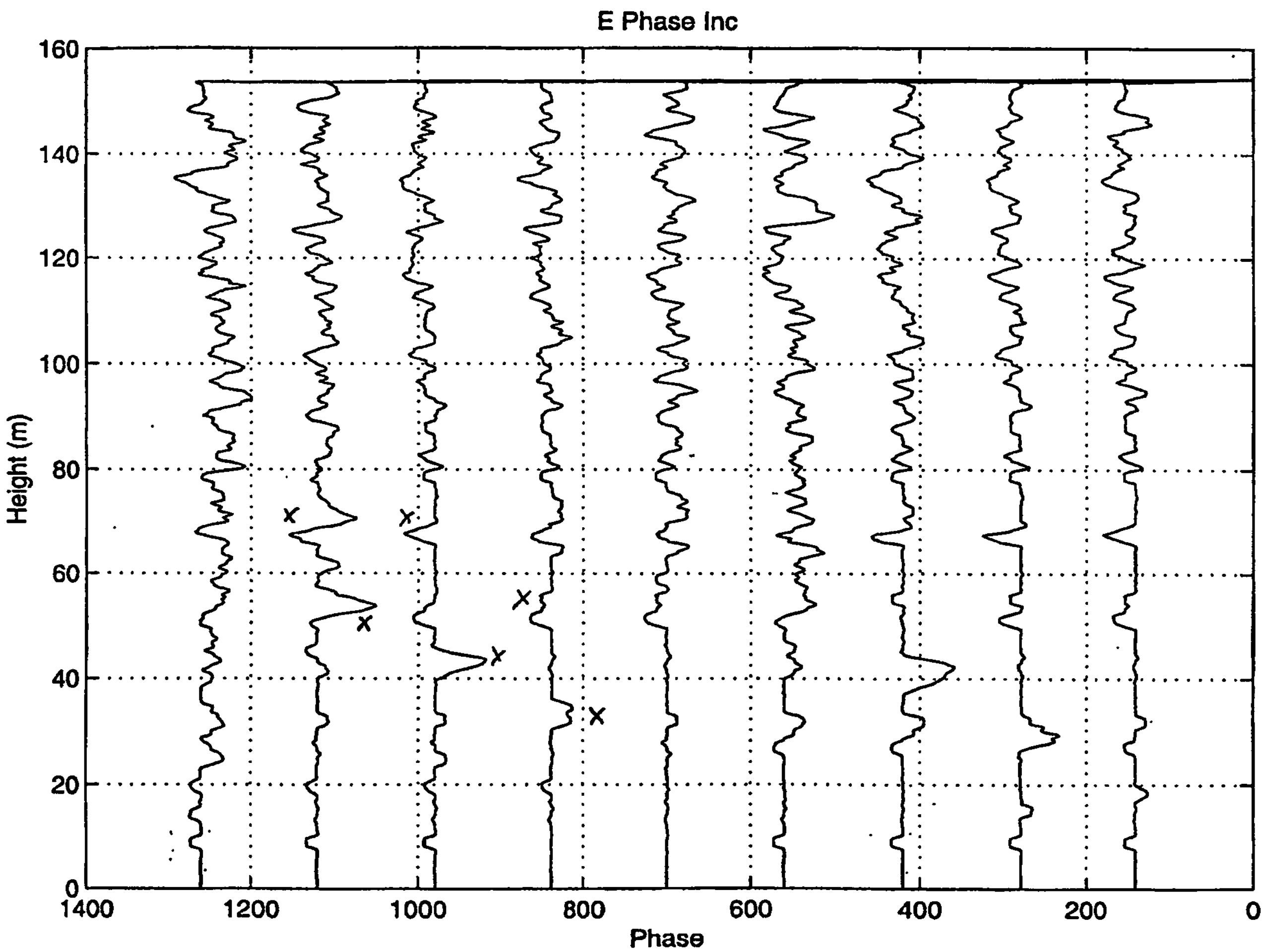


Fig. 1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160
140
120
100
80
60
40
20
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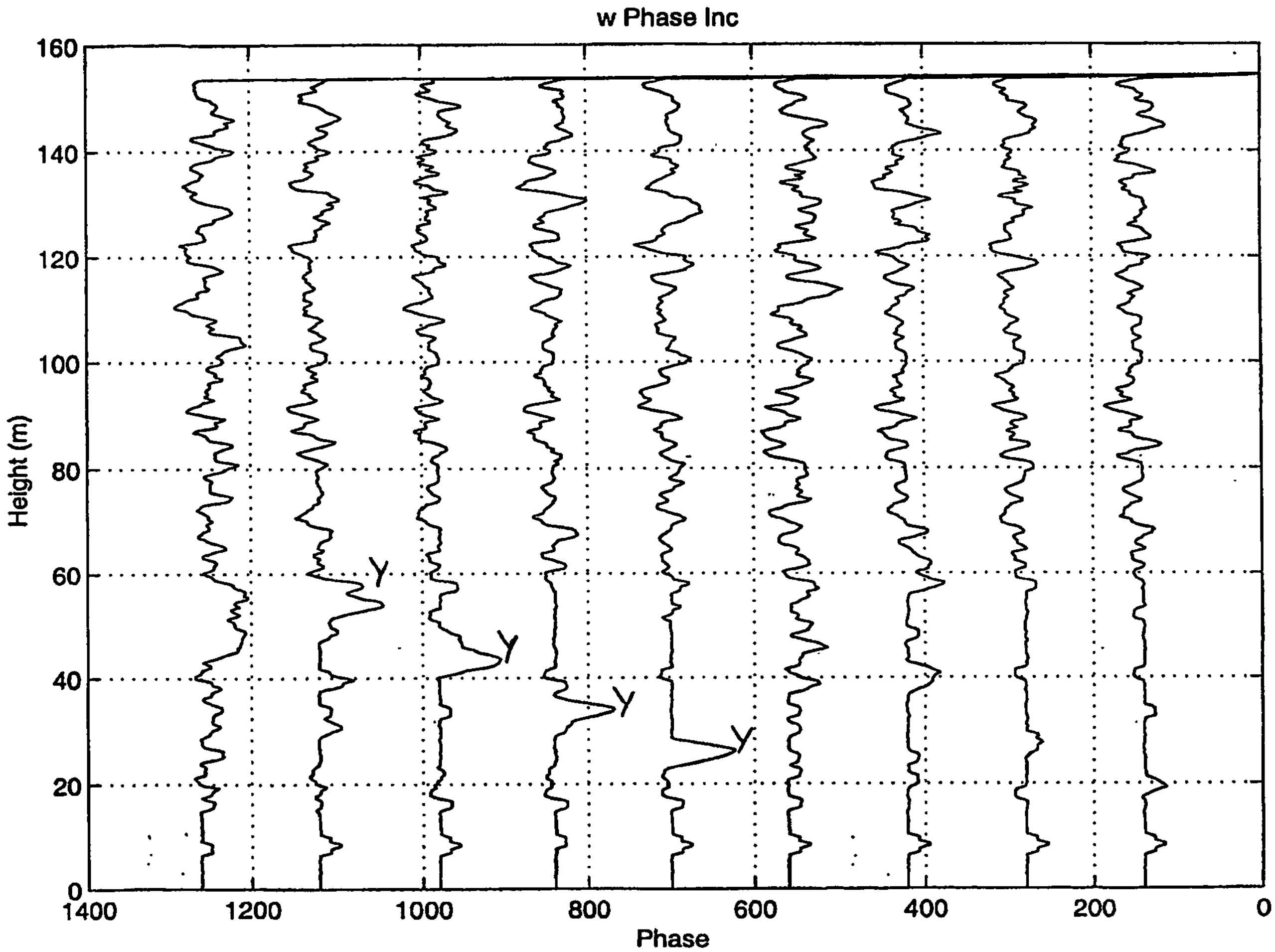
1200
1000
800
600
400
200
0
Phase

Fig. 2


w Phase Inc
Height (m)
Phase
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140
120
100
80
60
40
20
0
1400
1200
1000
800
600
400
200
0
Y
Y
Y
Y

Fig. 3

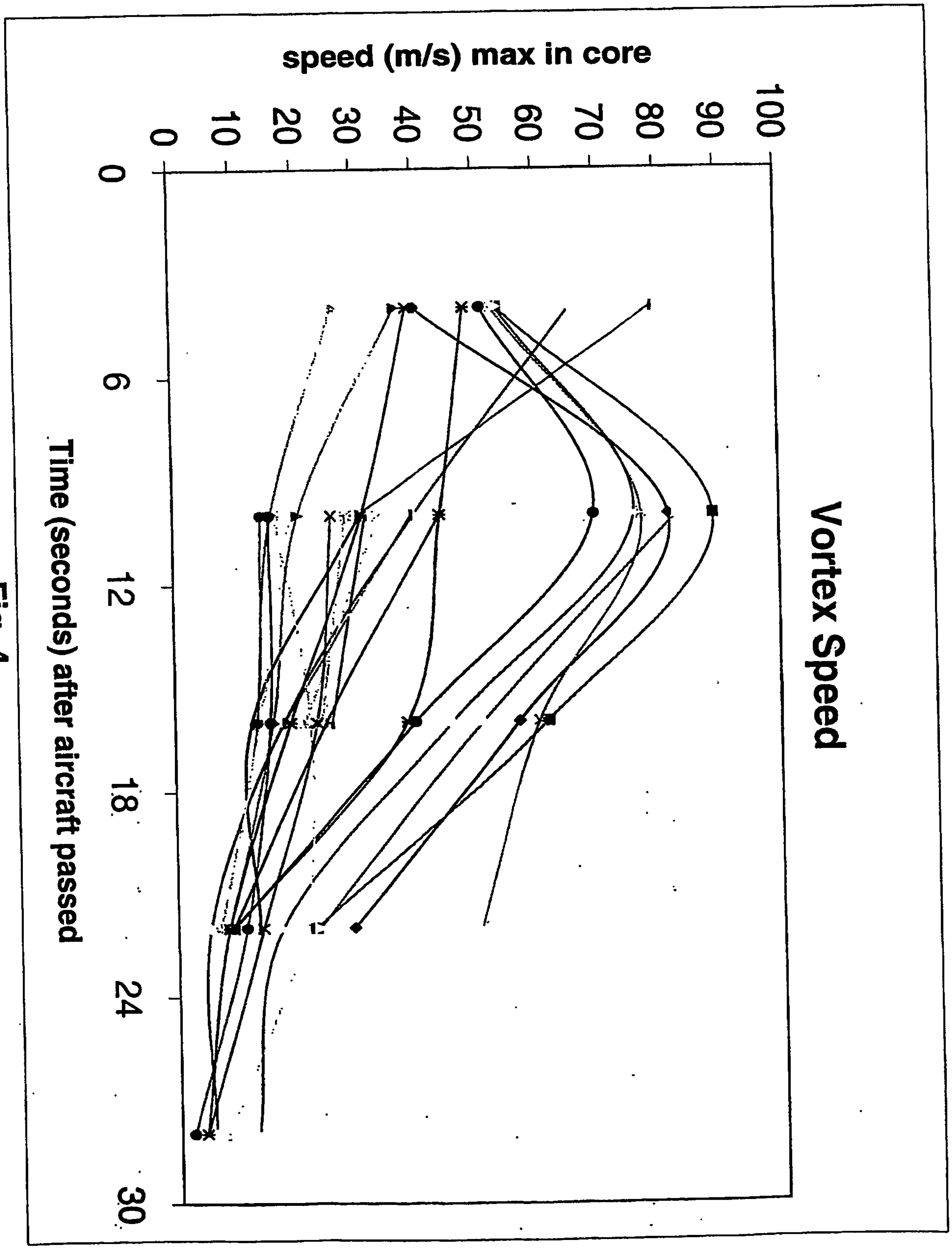
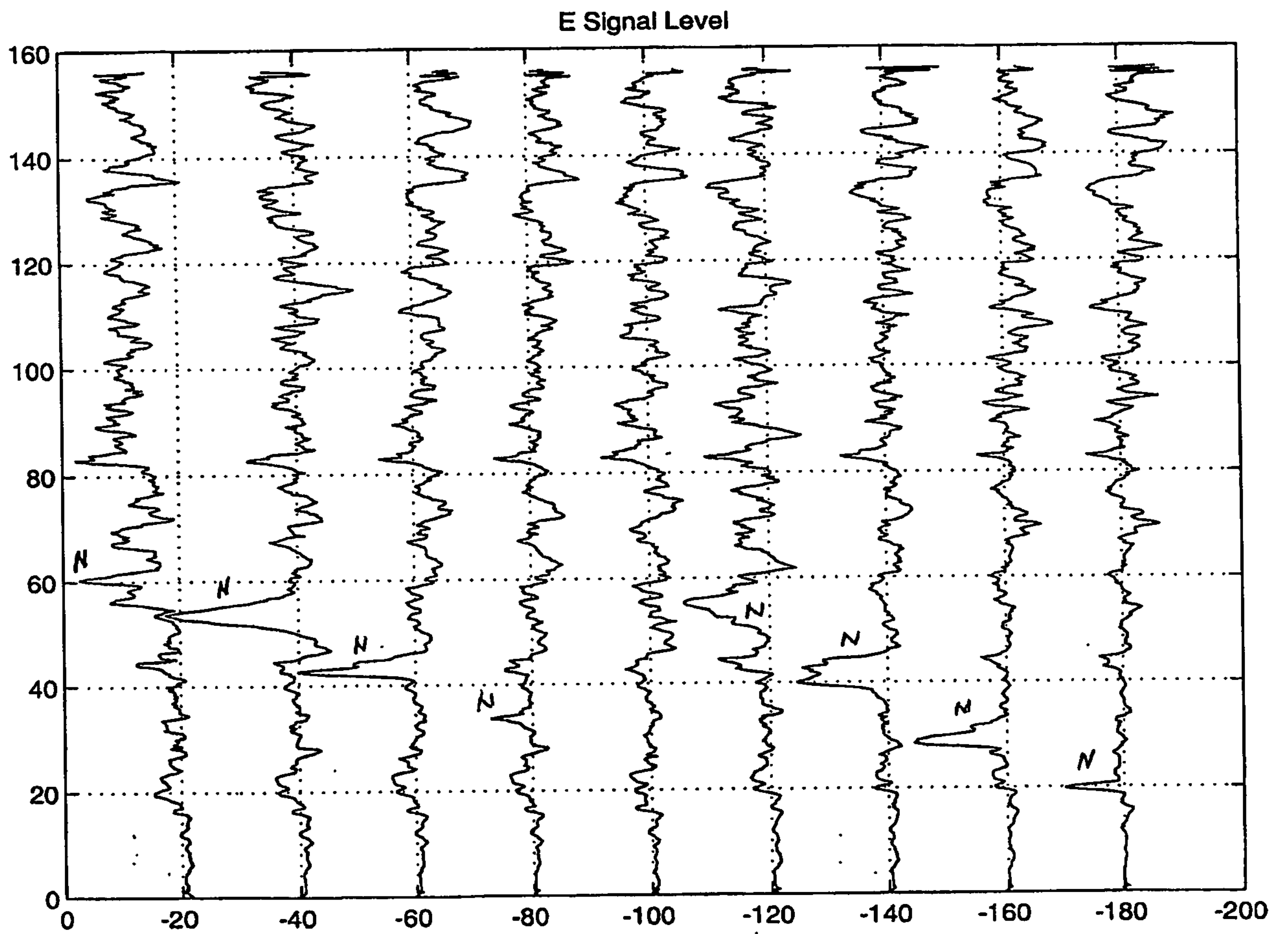

Vortex Speed
speed (m/s) max in core
0
10
20
30
40
50
60
70
80
90
100
0
6
12
18
24
30
Time (seconds) after aircraft passed

Fig. 4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120
100
80
60
40
20
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0
-20
-40
-60
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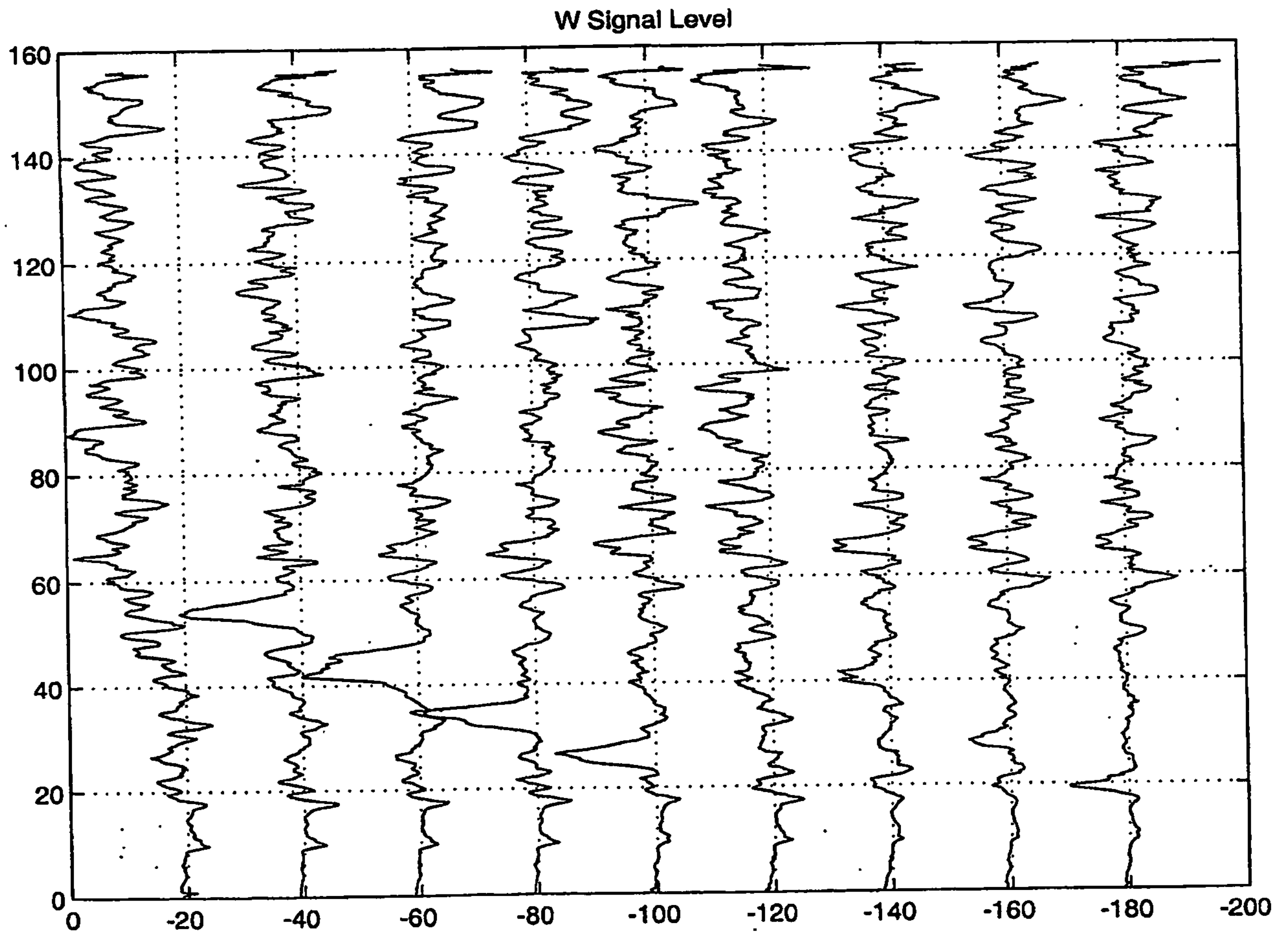
-140
-160
-180
-200
N
N
N
N
N
N
N
N
N

Fig. 5


W Signal Level
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120
100
80
60
40
20
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0
-20
-40
-60
-80
-100
-120
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-160
-180
-200

Fig. 6

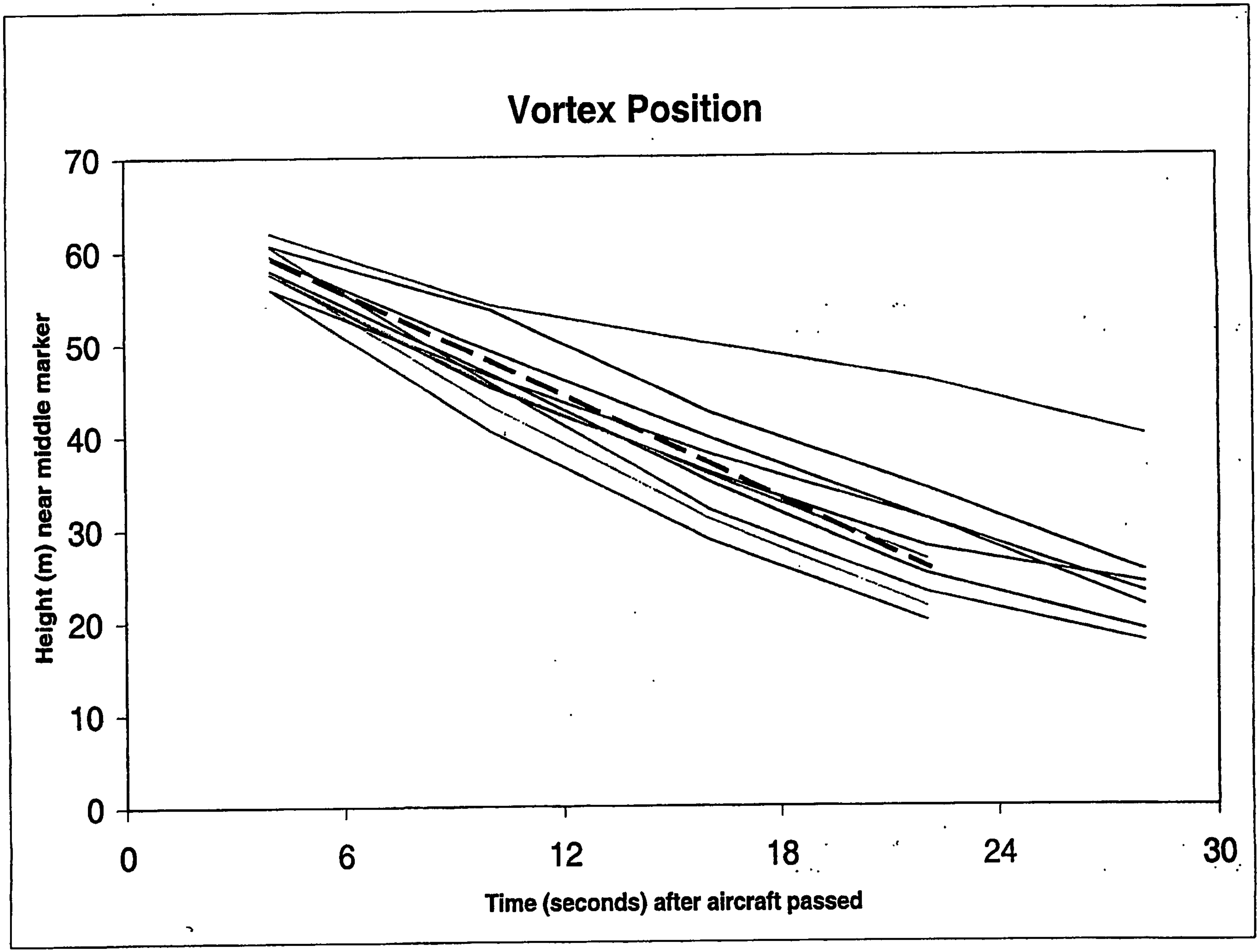
Vortex Position
Height (m) near middle marker
70
60
50
40
30
20
10
0
0
6
12
18
24
30
Time (seconds) after aircraft passed

Fig. 7